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Vermicomposting of cow dung, kitchen waste and sewage sludge with bagasse using Eisenia fetida

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Original Article

Abstract

The sugar cane industry produces significant amounts of cane trash and bagasse. Inappropriate disposal of agro-wastes can lead to environmental problems. Converting wastes such as cane trash and bagasse (Bg) to a fertilizer and conditioner is the aim of sustainable waste management in sugar cane industry. Cow dung (CD), kitchen waste (KW), and sewage sludge (SS) were mixed with bagasse as amendment in different proportions: Bg:CD (1:1), Bg:CD (1:2), Bg:SS (1:1), Bg:SS (1:2), Bg:KW (1:1) and Bg:KW (1:2) in triplicate treatment with *Eisenia fetida*. Chemical analysis of the samples showed a significant decrease in total organic carbon (TOC) (20%-54%), total Kjeldahl nitrogen (TKN) (9.5%-39.7%) and C:N ratio (12%-31.2%), while total potassium (31.4%-54%) and available phosphorus (32%-55%) contents increased during vermicomposting. A significant difference was observed among weight and number of worms in control with other treatments at the end of vermicomposting. According to obtained results vermicomposting is an efficient method for sustainable recycling different classes of waste produced in sugar cane agro-industry.

KEYWORDS: Vermicomposting, Bagasse, Cow Dung, Kitchen Waste, Sewage sludge, Eisenia Fetida

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Introduction

The sugar cane industry produces significant amounts of cane trash and bagasse. Bagasse is the milling by-product which remains after extracting sugar from the stalk. It is a fibrous residue that contains mainly cellulose, hemi cellulose and lignin. The inappropriate disposal of agro-wastes can lead to environmental problems. In Khuzestan province of Iran, there are more than 100,000 hectares sugarcane farms which produce 1,200,000 ton surplus bagasse[1] which can be used as bulking agent in co-composting and vermicomposting with other wastes. On the other side, every year million tons of livestock manures, kitchen wastes (KW) and sewage sludge (SS) are generated and disposed to land without any treatment which leads to major environment pollution in Khuzestan province.[2] Rich in nutrient and organic matter, they are welcome to be used as fertilizer to improve the land. Co-composting and vermicomposting could balance nutrients in different matrixes and obtained humus materials.

Vermicomposting is a cost-effective and environmentally sustainable technology in which worms and microorganisms under aerobic and mesophilic conditions convert organic matters to a nutrient-rich organic fertilizer and soil conditioner. Earthworms play an important role in treatment and

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biological degradation of substrate and maintaining aerobic condition.[3,4] Various studies have demonstrated vermicomposting of different organic wastes such as: tannery waste,[5] primary sewage,[6] apple pomace waste[7] and rice husk[8] and sugar industry wastes including press mud, trash and bagasse.[9-11] Pramanik[12] has investigated vermicomposting bagasse with coir and quantified fungal biomass and nutrient dynamics during vermicomposting. Pigatin et al. evaluated the chemical transformations of agricultural wastes during vermicomposting of cattle manure, orange peel and filter cake in São Carlos, Brazil.[13]

The aim of this study was vermicomposting cow dung (CD), kitchen waste and sewage sludge with bagasse as an amendment in order to produce an organic fertilizer for sugar cane industry and sustainable industrial solid waste development and management. Different combinations of bulky materials and wastes were selected in order to find out suitable waste mixture for optimizing earthworm activity. Efficiency of vermicomposting process and the compost quality was monitored through agrochemical properties and earthworm biomass.

Materials and Methods

Composting earthworms, Eisenia fetida, were prepared from Mehran Company, Ahvaz, Iran. Bagasse was provided from sugar cane development company, Ahvaz. Cow dung was collected from Kut Abdollah, a cow husbandry area around Ahvaz and kitchen waste was collected from Kouy Ostadan, a residential area in the campus of Ahvaz Jundishapour University of Medical Sciences. The treatments were composted for 3 weeks. The digested and dewatered sewage sludge was supplied from Choneibeh sewage treatment plant, Ahvaz.

Kitchen waste, cow dung and sewage digested sludge were mixed with chopped bagasse (1-1.5 cm diameter) as amendment in different ratio to prepare different vermibeds (Table 1). The experiment mixtures were carried out in 21 boxes with the dimensions of 0.4 m height × 0.6 m length × 0.35 m. The experimental vermibeds were used in triplicate for each treatment and a vermibed alone with bagasse in triplicate was used as experimental control. The weight of each treatment was 3 kg and sixty healthy earthworms were released into each experimental box. The experimental boxes were placed in dark room at room temperature (20-25 °C). Daily temperature changes were calculated as the mean of the values obtained from the five points of each pile using a mercury-in-glass thermometers. Moisture of mixtures was kept in the optimized level (60%-70%) during vermicomposting by spraying water.

Table 1. Description of vermibeds used for experimentations

Vermibed	Ratio (vol:vol)	Description
Bg (control)	1	Bagasse
Bg:CD-I	1:1	1 part bagasse:1 part cow dung
Bg:CD-II	1:2	1 part bagasse:2 part cow dung
Bg:SS-I	1:1	1 part bagasse:1 part sewage sludge
Bg: SS-II	1:2	1 part bagasse:2 part sewage sludge
Bg:Kw-I	1:1	1 part bagasse:1 part kitchen waste
Bg:Kw-II	1:2	1 part bagasse:2 part kitchen waste

Bg: Bagasse; CD: Cow dung; SS: Sewage sludge; KW: Kitchen waste

About 20 g homogenized wet samples (free from earthworms and cocoons) were drawn from each treatment and dried for chemical analysis at 0, 15, 30, 45 and 60 days. The changes in the population and weight of earthworms were measured at start up time and at the end time in each treatment. At the end of vermicomposting, earthworms were separated from the substrate material by hand sorting, then the body of worms was washed with tap water and counted and weighed.

The pH was measured in 1/10 (w/v) aqueous solution using a digital pH meter

(Eutech pH 1500).[14] Organic carbon was determined by ignition method,[15] total Kjeldahl nitrogen (TKN) was measured using the micro-Kjeldahl method.[16] Available phosphorus was measured by Olsen's method[17] and total potassium was determined by flame emission technique by flame photometer.[18]

Statistical analysis was conducted using SPSS software for Windows (version 16, SPSS Inc., Chicago, IL., USA). The results are the means of three replicates. One-way analysis of variance (ANOVA) was used to analyze the differences among treatments at a significance level of $P < 0.05$.

Results and Discussion

Physico-chemical analysis

The chemical analyses of vermibeds are reported in table 2. Data has revealed significant chemical changes in all vermibeds during vermicomposting.

pH is a limiting factor for the survival and growth of earthworms which could reversely affect their bed.[4] pH of the vermibeds ranged between 6.36 in control to 7.38 in Bg:CD-II treatment. As shown in table 2, pH reduced in all treatments during vermicomposting. Reduction of pH may be due to formation of ammonium (NH_4^+) ions,[19] presence of carboxylic and phenolic groups in humic acids, conversion of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates; production of intermediate species of organic acids, formation of CO_2 by microbial metabolism and volatile fatty acids and formation of organic acid by microbial decomposition.[20,21] The obtained results in this research were in line with findings of other researchers.[5,12,22]

Data in table 2 reveals a significant decrease ($P < 0.01$) in the TOC content in all the treatments during vermicomposting. The organic carbon content was lower in final product than initial level in the vermibeds. Reduction in TOC ranged from 20.5% in the control to 54% in the Bg:KW-II treatment. However, TOC loss in experimental control Bagasse (Bg) was less than other vermibeds. It is reported that combined interaction of earthworm and microorganisms through biochemical degradation of waste material, homogenization of the ingested material and adding mucus and enzymes to the ingested material leads to organic content loss in the form of CO_2 from the substrates during the decomposition of organic waste. In addition, some part of organic fractions are converted into worm biomass during vermicomposting.[23] Increasing the bulking agent proportion in the treatment of CD and SS increases the loss of carbon. It indicates that different physical and chemical composition and the proportion of amendment material in treatment substrates affects the rate of microbial enzymes production and their activities.[24] In a study by Suthar, 4.8%-12.7% loss of organic carbon as CO_2 was observed during vermistabilization of the sewage sludge mixed with sugarcane trash.[21] Our observations are supported by Suthar, who reported a similar loss of 12.7%-28% of TOC content during composting of vegetable-market solid waste.[21]

TKN (N-NH_4) was decreased in all vermibeds at the end of the process (Table 2). Final N content was 7.24 g kg^{-1} in (control) and 14.96 g kg^{-1} (Bg:SS-II) in vermicomposted mixtures. The decrease during vermicomposting, was possibly due to ammonification, ammonia volatilization, nitrification and denitrification.[25,26-28] Some researchers reported that converting some part of the available nitrogen into earthworm protein, led to lower nitrogen content in the final vermibeds.[8,29,30] Our findings are compatible with those obtained by Lim et al. who observed 23.7% loss of total nitrogen during vermicomposting of rice husk[8] but they are not in agreement with the results of some other researches that reported increase in total nitrogen during vermicomposting.[24,31] The differences between results may be related to initial N content of the used materials and pre-processing operations on used materials.

Table 2. Chemical characteristics of vermibeds (g kg−1) at start and at end of the experimentations (mean ± SD, n = 3)

	pH	Organic C (g/kg)	Total N (g/kg)	Available P (g/kg)	Total K (g/kg)	C:N ratio
Bg						
Initial	7.46 ± 0.06	516.71 ± 5.80	7.99 ± 0.90	0.02 ± 0.003	4.21 ± 0.1	64.59 ± 0.40
Final	6.36 ± 0.13	411.21 ± 4.80	7.24 ± 0.50	0.04 ± 0.001	6.14 ± 0.4	56.80 ± 0.20
Bg:CD (1:1)						
Initial	7.79 ± 0.03	488.07 ± 2.20	10.44 ± 0.30	0.08 ± 0.002	5.36 ± 0.5	46.79 ± 0.08
Final	7.16 ± 0.07	315.51 ± 3.60	7.76 ± 0.10	0.16 ± 0.003	9.32 ± 0.3	40.65 ± 0.40
Bg:CD (1:2)						
Initial	7.82 ± 0.04	475.23 ± 2.30	13.45 ± 0.20	0.09 ± 0.002	6.11 ± 0.2	35.32 ± 0.12
Final	7.38 ± 0.05	285.47 ± 6.10	10.45 ± 0.10	0.19 ± 0.001	11.51 ± 0.6	27.30 ± 0.60
Bg:SS (1:1)						
Initial	7.38 ± 0.19	449.55 ± 3.70	15.75 ± 0.04	0.08 ± 0.002	2.88 ± 0.5	28.54 ± 0.21
Final	6.80 ± 0.30	276.50 ± 2.60	11.51 ± 0.10	0.17 ± 0.003	4.72 ± 0.1	24.01 ± 0.10
Bg:SS (1:2)						
Initial	7.12 ± 0.10	431.30 ± 4.38	18.73 ± 0.20	0.09 ± 0.001	3.83 ± 0.1	23.11 ± 0.87
Final	6.67 e 0.20	255.21 ± 2.30	14.96 ± 0.30	0.2 ± 0.004	6.53 ± 0.2	17.05 ± 0.10
Bg:KW (1:1)						
Initial	7.21 ± 0.16	431.30 ± 4.38	11.26 ± 0.20	0.03 ± 0.007	6.91 ± 0.1	32.47 ± 0.15
Final	6.79 ± 0.15	182.12 ± 11.14	6.79 ± 0.70	0.07 ± 0.001	15.28 ± 0.3	26.80 ± 1.50
Bg:KW (1:2)						
Initial	7.12 ± 2.47	358.65 ± 2.68	14.60 ± 0.20	0.04 ± 0.001	8.85 ± 0.5	24.39 ± 0.13
Final	6.58 ± 2.62	164.92 ± 11.03	9.75 ± 0.40	0.08 ± 0.001	20.68 ± 0.6	16.90 ± 1.20

Bg: Bagasse; CD: Cow dung; SS: Sewage sludge; KW: Kitchen waste; C: Carbon; N: Nitrogen; P: Phosphorus; K: Potassium; C:N ratio: Carbon/nitrogen ratio; SD: Standard deviation

Concentrations of available phosphorus in final mixtures were higher than initial material in all treatments. The earthworm affects phosphorus mineralization in wastes during passing organic matter through its gut. Mineralization of phosphorus during vermicomposting was attributed to presence of phosphorus-solubilizing bacteria and increasing alkaline and acid phosphatase enzymes activities.[32] The highest increase in available phosphorus content was in Bg:SS-II (55.7%) followed by Bg:KW-II (52%), Bg:SS-I, Bg:KW-I (50%), Bg:CD-II (49%), Bg:CD-I (47%) and Bg (32%). Therefore, available phosphorus in vermicomposted material was higher than control treatment at the end. The phosphorus content of all treatments except control were not significantly different ($P \leq 0.05$). The difference among vermibeds for phosphorus mineralization rate could be due to different chemical and microbiological structure of substrate material.[33-35]

Concentration of the total potassium (TK) in final compost was higher than initial substrate and controls. TK content of treatments was in the range of 6.14 to 20.68 g kg $^{-1}$ (Table 2). Maximum and minimum TK content were recorded in the treatment of Bg:Kw-II and in the control respectively. The initial TK content in the feed mixtures was in the range of 2.8-8.80 g kg^{-1}. When organic matter passes through the gut of earthworms, unavailable potassium are transformed to more soluble forms with enhanced microbial activity, which therefore enhances the rate of mineralization.[36,37] Similar results on potassium increment have been reported by other researchers.[36,38,39] Decomposition of organic material by microorganisms produces acid products that increases the available soluble potassium. On the other hand, the gut of earthworm have a big population of microflora that could enhance potassium content in obtained vermicompost.[40,41]

The carbon/nitrogen (C:N) ratio is an important indicator for maturity of organic wastes and its changes reflect the degree of mineralization and stabilization during the process of vermicomposting. The C:N ratios

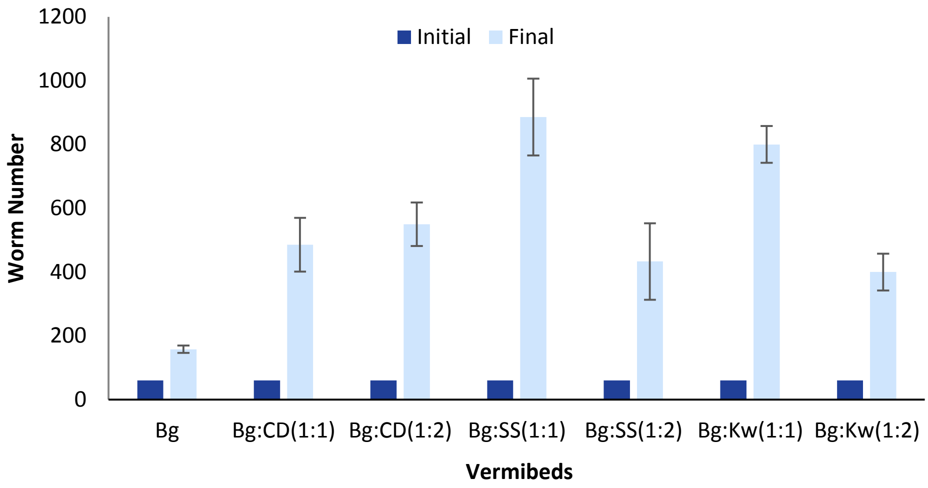

Figure 1. Initial and final number of worms during experimentations
Bg: Bagasse; CD: Cow dung; SS: Sewage sludge; KW: Kitchen waste

of substrate materials showed a decrease considerably during vermicomposting. The highest decrease in C:N ratio was in Bg:KW-II (31%) followed by Bg:SS-II (26%), Bg:CD-II (22%), Bg:KW-I (18%), Bg:SS-I (15%), Bg:CD-I(13%) and control (11%). Final C:N ratios of final products were in the range of 16.9 ± 1.2 (Bg:KW-II) to 56.8 ± 0.2 (control). The reduction in the C:N ratio during composting time may attributed to biochemical degradation and release of organic carbon in the form of CO_2.[6,30] Reduction in C:N ratio was recorded during vermicomposting of different wastes.[6,21,42]

The quality of final compost in the treatment of Bg:SS (1:2) was better than other treatments and it could be applied as soil conditioner in agriculture and soil remediation. Treatment with higher amendment ratio obtained better quality due to better aeration with increasing amendment.

Earthworm production rate

The production rate of worms is used as a biological indicator for monitoring vermicomposting operation.[43] During the experimental period, worms grew well in all the treatments and no mortality was observed in any one. Changes in the population and the mass of worms in different vermibeds during time is given in figures 1 and 2.

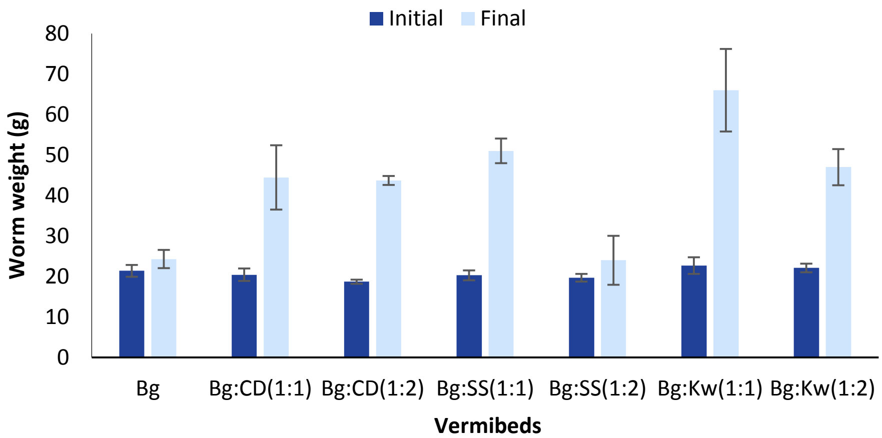

Figure 2. Initial and final weight of worms during experimentations
Bg: Bagasse; CD: Cow dung; SS: Sewage sludge; KW: Kitchen waste

There was an increase in biomass gain in all vermibeds during the vermicomposting. The greater weight and number of earthworm gain percentage was observed in Bg:KW-I and Bg:SS-I (Figures 1 and 2). The weight gain ($F = 59.24$, $P < 0.05$) and number gain ($F = 125.58$, $P < 0.05$) were significant in control compared to other treatments. The treatment mixtures with the proportion of 1:1 produced the highest biomass. Different biomass gain in control experiments, was due to composition and quality of wastes such as palatability, particle size, protein and crude fiber contents that could influence the earthworm growth trends in waste mixtures during vermicomposting. Worms production rate during vermicomposting depends on available nutrient and microbial population in vermibeds.[30,31,34].

Conclusion

Mixing of bagasse as bulking agent with cow dung, sewage sludge and kitchen waste improved vermicomposting process significantly. The content of Phosphorus and TK increased during vermicomposting compared with the bagasse treatment alone, and the organic carbon content and TKN decreased during vermicomposting. Biomass gain in all vermibeds during the vermicomposting was increased. The greater weight and number of earthworm gain percentage was observed in Bg:KW-I and Bg:SS-I.

Conflict of Interests

Authors have no conflict of interests.

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References

1. Najafi G, Ghobadian B, Tavakoli T, Yusaf T. Potential of bioethanol production from agricultural wastes in Iran. Renew Sust Energ Rev 2009; 13(6-7): 1418-27.
2. Alavi N, Amir-Heidari P, Azadi R, Babaei AA. Effluent quality of ammonia unit in Razi petrochemical complex. J Advan Environ Health Res 2013; 1(1): 15-20.
3. Kaushik P, Garg VK. Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm Eisenia foetida. Bioresour Technol 2003; 90(3): 311-6.
4. Singh RP, Embrandiri A, Ibrahim MH, Esa N. Management of biomass residues generated from palm oil mill: Vermicomposting a sustainable option. Resour Conserv Recy; 2011; 55(4): 423-34.
5. Ravindran B, Contreras-Ramos SM, Sekaran G. Changes in earthworm gut associated enzymes and microbial diversity on the treatment of fermented tannery waste using epigeic earthworm Eudrilus eugeniae. Ecol Eng 2015; 74: 394-401.
6. Hait S, Tare V. Vermistabilization of primary sewage sludge. Bioresour Technol 2011; 102(3): 2812-20.
7. Hanc A, Chadimova Z. Nutrient recovery from apple pomace waste by vermicomposting technology. Bioresour Technol 2014; 168: 240-4.
8. Lim SL, Wu TY, Sim EYS, Lim PN, Clarke C. Biotransformation of rice husk into organic fertilizer through vermicomposting. Ecol Eng 2012; 41: 60-4.
9. Sen B, Chandra TS. Chemolytic and solid-state spectroscopic evaluation of organic matter transformation during vermicomposting of sugar industry wastes. Bioresour Technol 2007; 98(8): 1680-3.
10. Kumar R, Verma D, Singh BL, Kumar U, Shweta. Composting of sugar-cane waste by-products through treatment with microorganisms and subsequent vermicomposting. Bioresour Technol 2010; 101(17): 6707-11.
11. Sangwan P, Kaushik CP, Garg VK. Vermicomposting of sugar industry waste (press mud) mixed with cow dung employing an epigeic earthworm Eisenia fetida. Waste Manag Res 2010; 28(1): 71-5.
12. Pramanik P. Changes in microbial properties and nutrient dynamics in bagasse and coir during vermicomposting: quantification of fungal biomass through ergosterol estimation in vermicompost. Waste Manag 2010; 30(5): 787-91.
13. Pigatin LB, Atoloye IA, Obikoya OA, Borsato AV, Rezende MO. Chemical study of vermicomposted agroindustrial wastes. Int J Recycl Org Waste Agricult 2016; 5(1): 55-63.
14. United States Environmental Protection Agency. Soil and Waste pH [Online]. [cited 2004]; Available from: URL: https://www.epa.gov/sites/production/files/2015-12/documents/9045d.pdf
15. Nelson D, Sommers LE. Total carbon and organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR, Editors. Methods of soil analysis.

Madison, WI: American Society of Agronomy; 1996. p. 539-79.
16. Bremner JM. Nitrogen-total. In: Sparks DL, Editor. Methods of soil analysis part. 3. chemical methods, soil. Madison, WI: Soil Science Society of America; 1996. p. 1085-121.
17. Olsen SR, Cole C, Watanabe F, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington, DC: U.S. Dept. of Agriculture; 1954.
18. Santhi R, Natesan R, Bhaskaran A, Murugappan V. Procedures for soil testing and water quality appraisal. Coimbatore, India: Tamil Nadu Agricultural University; 2003.
19. Alavi N, Azadi R, Jaafarzadeh N, Babaei A. Kinetics of Nitrogen Removal in an Anammox Up-Flow Anaerobic Bioreactor for Treating Petrochemical Industries Wastewater (Ammonia Plant). J Asian Chem 2011; 23(12): 5220-4.
20. Ndegwa PM, Thompson SA, Das KC. Effects of stocking density and feeding rate on vermicomposting of biosolids. Bioresour Technol 2000; 71(1): 5-12.
21. Suthar S. Vermistabilization of municipal sewage sludge amended with sugarcane trash using epigeic Eisenia fetida (Oligochaeta). J Hazard Mater 2009; 163(1): 199-206.
22. Plaza C, Nogales R, Senesi N, Benitez E, Polo A. Organic matter humification by vermicomposting of cattle manure alone and mixed with two-phase olive pomace. Bioresour Technol 2008; 99(11): 5085-9.
23. Suthar S. Nutrient changes and biodynamics of epigeic earthworm Perionyx excavatus (Perrier) during recycling of some agriculture wastes. Bioresour Technol 2007; 98(8): 1608-14.
24. Suthar S. Recycling of agro-industrial sludge through vermitechnology. Ecol Eng 2010; 36(8): 1028-36.
25. Babaei AA, Azadi R, Jaafarzadeh N, Alavi N. Application and kinetic evaluation of upflow anaerobic biofilm reactor for nitrogen removal from wastewater by Anammox process. Iranian J Environ Health Sci Eng 2013; 10(1): 20.
26. Sanchez-Monedero MA, Roig A, Paredes C, Bernal MP. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresour Technol 2001; 78(3): 301-8.
27. Kumar R, Shweta. Enhancement of wood waste decomposition by microbial inoculation prior to vermicomposting. Bioresour Technol 2011; 102(2): 1475-80.
28. Benitez E, Nogales R, Elvira C, Masciandaro G, Ceccanti B. Enzyme activities as indicators of the stabilization of sewage sludges composting with Eisenia foetida. Bioresour Technol 1999; 67(3): 297-303.
29. Fernandez-Gomez MJ, Romero E, Nogales R. Feasibility of vermicomposting for vegetable greenhouse waste recycling. Bioresour Technol 2010; 101(24): 9654-60.
30. Khwairakpam M, Bhargava R. Bioconversion of filter mud using vermicomposting employing two exotic and one local earthworm species. Bioresour Technol 2009; 100(23): 5846-52.
31. Deka H, Deka S, Baruah CK, Das J, Hoque S, Sarma NS. Vermicomposting of distillation waste of citronella plant (Cymbopogon winterianus Jowitt) employing Eudrilus eugeniae. Bioresour Technol 2011; 102(13): 6944-50.
32. Busato JG, Lima LصS, Aguiar NةO, Canellas LP, Olivares FةL. Changes in labile phosphorus forms during maturation of vermicompost enriched with phosphorus-solubilizing and diazotrophic bacteria. Bioresour Technol 2012; 110: 390-5.
33. Suthar S. Vermicomposting of vegetable-market solid waste using Eisenia fetida: Impact of bulking material on earthworm growth and decomposition rate. Ecol Eng 2009; 35(5): 914-20.
34. Suthar S, Mutiyar PK, Singh S. Vermicomposting of milk processing industry sludge spiked with plant wastes. Bioresour Technol 2012; 116: 214-9.
35. Xing M, Lv B, Zhao C, Yang J. Towards understanding the effects of additives on the vermicomposting of sewage sludge. Environ Sci Pollut Res Int 2015; 22(6): 4644-53.
36. Gupta R, Garg VK. Vermiremediation and nutrient recovery of non-recyclable paper waste employing Eisenia fetida. J Hazard Mater 2009; 162(1): 430-9.
37. Yadav A, Garg VK. Feasibility of nutrient recovery from industrial sludge by vermicomposting technology. J Hazard Mater 2009; 168(1): 262-8.
38. Suthar S. Potential utilization of guar gum industrial waste in vermicompost production. Bioresour Technol 2006; 97(18): 2474-7.
39. Kaushik P, Garg VK. Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. Bioresour Technol 2004; 94(2): 203-9.
40. Kaviraj, Sharma S. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. Bioresour Technol 2003; 90(2): 169-73.
41. Pramanik P, Ghosh GK, Ghosal PK, Banik P. Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresour Technol 2007; 98(13): 2485-94.
42. Manna MC, Jha S, Ghosh PK, Acharya CL. Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition. Bioresour Technol 2003; 88(3): 197-206.
43. Garg VK, Suthar S, Yadav A. Management of food industry waste employing vermicomposting technology. Bioresour Technol 2012; 126: 437-43.